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Dated 18 March 2004

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15 NOV 2000
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The Patent Office

16NOV00 E584038-17 D02917
P01/7700 0.00-0027888.7

Request for grant of a patent

The Patent Office
Cardiff Road
Newport
South Wales NP10 8QQ

1. Your reference

1842501/AM

2. Patent Application Number 15 NOV 2000 **0027888.7**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

RaceTrace Inc.
1601 Trapelo Road
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Patents ADP number *(if known)* 08023764001

If the applicant is a corporate body, give the country/state of its incorporation

Country: **USA**
State: **Delaware**

4. Title of the invention

PHASE BASED TAG TRACKING SYSTEM

5. Name of agent **Beresford & Co**

"Address for Service" in the United Kingdom to which all correspondence should be sent

2/5 Warwick Court
High Holborn
London WC1R 5DH

Patents ADP number 00001826001

6. Priority details

Country	Priority application number	Date of filing

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier application | Date of filing

8. Is a statement of inventorship and or right to grant of a patent required in support of this request?

YES

9. Enter the number of sheets for any of the following items you are filing with this form.

Continuation sheets of this form	
Description	**10** + 10 RN
Claim(s)	
Abstract	
Drawing(s)	

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents form 7/77)*	**1 + 2 COPIES**
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for Substantive Examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application

Signature Beresford & Co   Date 15 November 2000

BERESFORD & Co

12. Name and daytime telephone number of person to contact in the United Kingdom

Alan MacDougall

Tel: 020 7831 2290

Patents Form 7/77

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(Rule 15)

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Statement of inventorship and of right to grant of a patent

The Patent Office

Cardiff Road
Newport
South Wales NP10 8QQ

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1. Your reference

1842501/AM

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2. Patent Application Number

accompanying application reference 1842501 15 NOV 2000 **0027888.7**

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3. Full name of the or each applicant

RaceTrace Inc.

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4. Title of the invention

PHASE BASED TAG TRACKING SYSTEM

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5. State how the applicant(s) derived the right from the inventor(s) to be granted a patent

By virtue of the employment of David Bartlett by Scientific Generics Limited and the employment of Peter Duffett-Smith by Cambridge Positioning Systems Limited and by virtue of an agreement between Scientific Generics Limited, Cambridge Positioning Systems Limited and the applicant.

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6. How many, if any additional Patents Forms 7/77 are attached to this form?

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7. I/We believe that the person(s) named over the page (and on any extra copies of this form) is/are the inventor(s) of the invention which the above patent application relates to.

Signature Beresford & Co Date 15 November 2000

BERESFORD & Co

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8. Name and daytime telephone number of person to contact in the United Kingdom

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Patents Form 7/77

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1 **Phase Based Tag Tracking System**

2 BACKGROUND

Radio signals have been and continue to be used extensively for the purpose of locating and tracking objects.

For location the position is normally computed by analysing signals that are received from two or more different geographically dispersed transmitters. There are a number of different techniques for doing this, including CURSOR as defined in EP0303371 and the commercially available GPS system. The various techniques include time-of-flight or phase measurement and may or may not require the transmitter network to be synchronised.

Tracking an object may be accomplished using the same techniques as for location and sending the result to a monitoring point remote from it. However, more usually the object has a transmitter that emits a radio signal. The location of the source of the radio signal is identified using a number of different techniques including direction finding using directional antennae or arrays of receivers that enable the difference in the time-of-arrival or phase of the received signal to be measured and hence the location to be computed.

This invention describes a new system for tracking a tag's position in real time by measuring the phases of the radio signals emitted by the tag. The tag is the device attached to the object, the location of which is required.

3 DESCRIPTION OF THE INVENTION

The main elements of the Tracking System are:

- It consists of a number of independent receivers geographically dispersed, the number being at least equal to the number of dimensions required for tracking the tag. So to track in two dimensions at least two receivers are required. The receivers are fixed in known geographic locations.
- Each tag being tracked includes a transmitter that transmits a radio signal receivable by a number of receivers in the network at least equal to the number of dimensions required for tracking. The tag is mobile and may move.
- The fixed receivers receive the signal transmitted by the mobile tag and measure the phase of the signal.
- The measurements made by the receivers are communicated to a device (Position processor) which compares the measurements from the different receivers and derives the location of the tag. The position processor may be located with one of the receivers or at a separate location.
- The signal transmitted by the tag may be a CW narrow-band radio transmission and the receivers measure the received phase of this signal.
- The signal whose phase is being measured could be a signal modulated on a higher frequency carrier rather than the carrier itself.
- The choice of CW signal frequency (or modulating frequency) depends on the accuracy required and the area of coverage within the cyclic ambiguity of the signal wavelength. The cyclic ambiguity places the distance from any particular receiver on one of a multiplicity of concentric circles.
- The indeterminate phase of the respective oscillators at power-on leads to the need for initial calibration of the transmitter. Once calibrated (or initialised) the system is able to track the tag position continuously and without cumulative error.
- The tags may transmit on a time division basis (or be interrupted) provided that successive transmissions remain phase continuous with one another, and that the phase "twist" between successive measurements is less than half a cycle.
- The transmitted signal may consist of two harmonically related CW tones locked to the same fundamental signal, where the signal phase used for measurement purposes is the difference between the two, rather than the phase of just one. For example two tones *a* and *b* may be chosen such that *a-b* is 1MHz, giving a wavelength of 300m.

- The dual tone system may be up-converted in the tag using a mixer (multiplication) for transmission in any radio band, and then converted back down to baseband (once again using a mixing process) in the receivers, without destroying the basic phase measurement (the phase relationship between the two tones), and without the need to phase lock the local oscillators used for transmit and receive.
- Extending the dual tone system to incorporate three tones such that the difference frequencies *a-b* and a-c are significantly different (for example 100kHz and 5MHz), allows the cyclic ambiguity of the measurement of phase to be unique over a much larger area - at least equal to the wavelength of the smaller difference frequency - and yet providing the resolution of the higher difference frequency.
- The signal could be modulated in order to convey information from the tag to the receiver network. In this case only the carrier of the signal is used for calculating the tag position.
- In the case that the network of receivers are synchronised, but the mobile tag transmitter is not, a third receiver is required in order to resolve the clock offset between transmitter and receiver network.
- The network of receivers does not need to be syncronised: syncronisation can be achieved by using an additional transmitter (similar to the tag) installed at a known location. It could be co-located with one of the receivers or at a unique location, provided that the reference transmitter location is known.

4 APPLICATIONS

The system described may be used for a variety of different applications in which the location of a tag needs to be known by the system. It is ideal for systems operating within a defined area, and which require continuous real time tracking of the tag. It could also be used in applications in which the location of the tag is relayed back to the tag using a communications link. The low complexity level enables the tag to be made extremely small and cheap.

5 TECHNOLOGY

This section describes an architecture and implementation for such a TS (Tracking System.

5.1 Architecture

The proposed TS architecture for tracking applications consists of:-

- A number of mobile units (RUs),
- three or more radio receivers at known locations,
- A TS Base unit (BU), which could also be described as a Fixed RU, located at a known position,
- A TS position processor (PP) which could be separate from the rest of the network.

This architecture is illustrated in Figure 1 below.

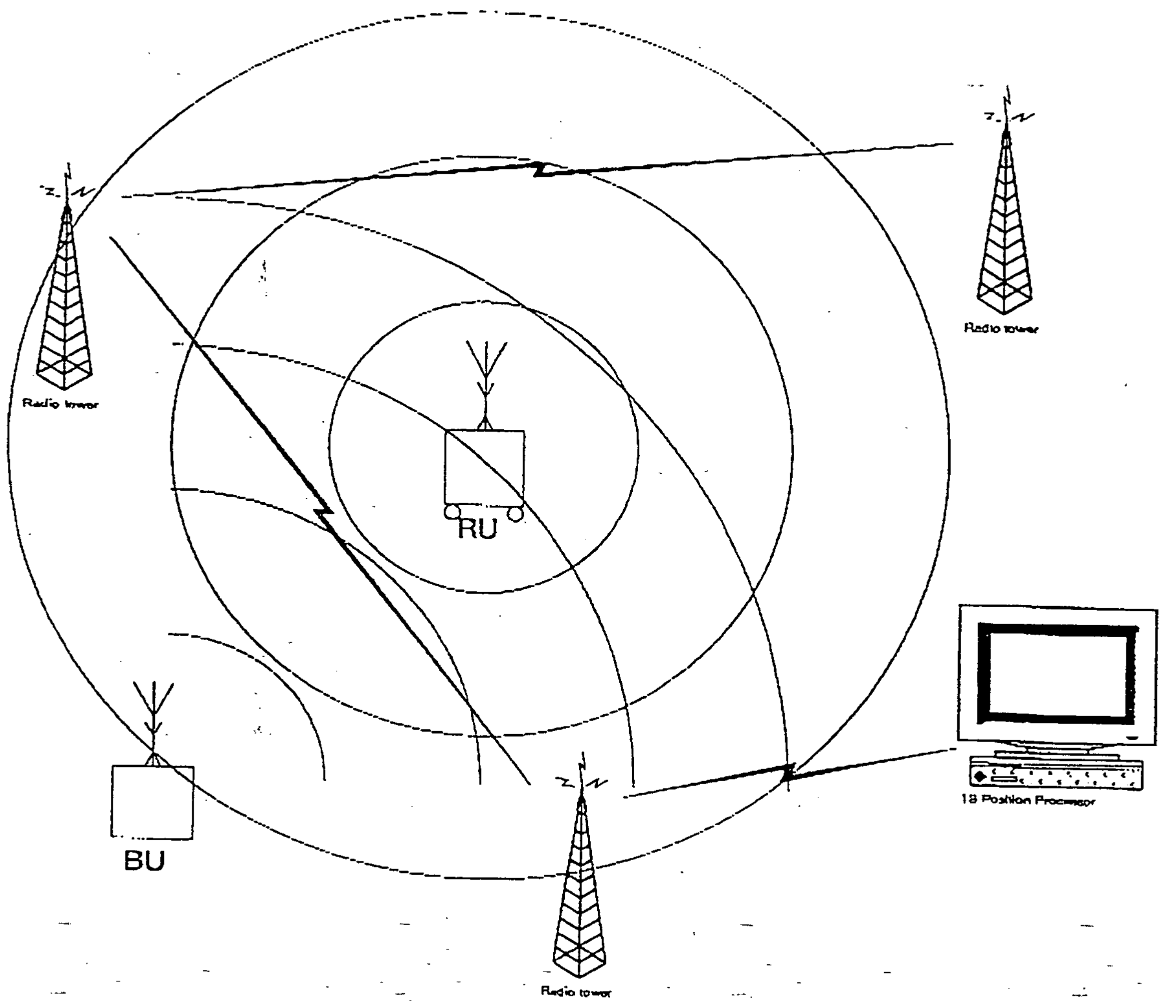

Figure 1 - TS Architecture

5.2 System Description

Each RU transmits a radio signal consisting of one or more unmodulated carriers. The BU transmits a signal in the same way as the RUs. Each RU is set to operate on a different frequency, or alternatively operate on a time based duty cycle, in order to distinguish between the different units.

The signal from each RU is received at all (or at least a sufficient number) of radio receivers, which also simultaneously receive the signal from the BU. This enables each radio receiver to derive measurements representing the differences between the signals from each RU and the BU.

The difference measurements are communicated back to the PP which is then able to derive the positions of each RU relative to the BU, using the position processing algorithms.

Thus the system needs to be supported by a communications network linking the TS receivers and the PP. This network may optionally also connect with the BU for purposes of management and support.

5.3 Initial Position Determination

Being able to determine the initial position of a RU, is considered the most important technical problem requiring solution in order for the TS to be commercially and practically viable.

Assuming a typical operating area having linear dimensions up to 3km, and an operating frequency of 3MHz, there are 30 signal wavelengths and hence considerable possible ambiguity in position. Operating at a frequency of 100kHz would very nearly solve the cyclic ambiguity problem, but would yield a far lower location accuracy. (30m estimated.)

A solution appears to be to use a combination of frequencies: the lower giving a coarse fix enabling the cyclic ambiguity of the higher to be resolved, and the higher providing the better location accuracy. Thus one could use frequency pairs such as:

- 100kHz and 3MHz (good for up to 3km and ~3m accuracy)
- 30kHz and 1MHz (good for up to 10km and ~6m accuracy)

Each pair of frequencies would need to be synthesised from a stable oscillator based on the lowest common demoninator frequency.

5.4 Frequencies and RF Planning

5.4.1 General Considerations

The most attractive licence exempt frequencies in the UK appear to be:

- 2.45GHz. Used for LANs, 83MHz available. Good for short range - probably one or two kilometre given an uncluttered environment, or 100m in wooded areas.
- 870MHz. 2MHz available but fragmented in terms of power available etc.
- 173MHz. 1MHz available, low power - probably good for a few kilometres in good propagation conditions.
- 5GHz. There is between 150MHz and 350MHz spectrum potentially available between 5GHz and 6GHz. The band is earmarked for LAN type applications requiring higher bandwidths than the 2.45GHz band can support.

In order to achieve the ideal operating frequency of around 1MHz to 10MHz, the signal could be derived as the difference between two synchronously generated carriers spaced this distance apart. In order to achieve the dual frequency operation required for IPD, three carriers will be required. Thus a RU could transmit the following frequency triples for example:

- f, f+0.1MHz, f+3.0MHz or f, f+2.9MHz, f+3.0MHz
- f, f+0.03MHz, f+1.00MHz or f, f+0.97MHz, f+1.00MHz

The separation required suggests that the most appropriate band may well be the 2.45GHz band. This is also the most universally available world wide allowing access to many markets in addition to the UK.

5.4.2 The 2.45GHz Band

This band is primarily used for LAN type applications. The devices operating in it generally use spread spectrum techniques - either frequency hopping or direct sequence. Depending on the implementation it is normally divided into channels. A common channel bandwidth is 1MHz. This would suit the TS well as the RUs could be interleaved using two (or pairs of) 1MHz channels which are either adjacent, or separated by 3MHz or more.

The carrier spacing would be dictated largely by the required stability of the local oscillator in the RU. A 4ppm oscillator would yield ±10kHz on the transmitted carrier. This would allow RUs to operate on a 30kHz spacing. This allows 20 RUs to share two

1MHz channels. A 1ppm oscillator would give ±2.5kHz and would allow a 10kHz spacing, yielding 60 RUs sharing the channel pair. Careful frequency planning should allow this to be increased to at least 80.

Theoretically, using all 42 channel pairs would allow more than 3000 unique RUs.

The regulations governing use of the band may restrict the system to a transmit duty cycle as low as 1% or a few %. Provided the reference oscillator is not shut down between transmissions this should not affect the operation of the TS. On the positive side it will reduce RU power consumption and also the chance of interference with other devices using the band.

5.5 Implementation

5.5.1 RU Design

The RU would be implemented as a compact battery powered device. In this implementation it would be a transmit only device. The requirements for size, battery life, operating range, update rate and cost would be traded off against one another to achieve an application specific performance profile for the particular RU.

A RU operating in the 2.45GHz band should be no larger or heavier than a conventional pager device. Being transmit only it is extremely simple.

5.5.2 The TS Receiver Units

These are receive only, but they need to be able to receive and simultaneously process the signals from a large number of RUs. In the simplest system this could be as few as 20, but in larger more complex implementations up to 1000 are envisaged.

It is likely that the Receiver will use digital software radio techniques to capture two to ten 1MHz channels (up to 10MHz bandwidth) from which the independent TS carriers will be extracted and offset against the reference BU(s).

The Receiver units will need to be permanently, or semi-permanently, installed and may need a mains power supply. It is possible that a portable version of the receiver could be built for short term use in covering specific areas.

In addition to the TS processing there are two further requirements on the receiver units:

- They need a communications channel with the PP,
- Their locations need to be accurately known.

These aspects of the system implementation are covered in the following sections of this document.

5.5.3 The CBU

The BU could be viewed as a RU installed at a fixed location. However, in addition to the need to know accurately where it is, there may be advantages in linking it to the communications network connecting the Receivers to the PP. It is also likely that it will need a permanent, or semi-permanent, installation and mains power.

5.5.4 The Communications Network

For a system operating in the 2.45GHz band it would make sense to use the same band for communications with the PP. It would probably mean losing the TS receive function during data transmit, but this would be a short duration outage that should not adversely affect overall system performance. Since only one receiver would be affected at any one instant, there should still be enough operating to provide continuous coverage of most RUs.

Standard 2.45GHz LAN components fitted with directional antennas would be used.

5.5.5 Receiver and CBU Location

For a permanently installed system these would be surveyed in a one-off operation during system installation.

However, as an alternative, the Receivers and BU could be co-equipped with Differential GPS receivers. The reference GPS (probably at the BU) would be accurately located and the differential corrections would then be transmitted to the other units using the existing communications network. This would allow temporary Receiver installations to be done with minimum difficulty.

5.6 Position Processor

Logically the Position Processor can be separated from the RUs, BU and Receiver elements. In practise it may be physically linked with one of these units.

For systems having large numbers of RUs, it is felt advantageous to separate the computation of the RU locations from the extraction of the RU data relative to the BU, as this function may be closely linked with the application.

This separation also provides a small amount of security against eavesdropping on data exchanges between RUs, Receivers, BU and PP in the network.

5.7 Summary

The system described could operate in any of the bands suggested, although the characteristics of each system would differ. The 2.45GHz band appears to result in the most flexible solution, although it suffers some restrictions. The most useful alternative is thought to be 173MHz.

Using the 2.45GHz band provides a system with the following key attributes:

- Only a single band is required and it would be used for both TS location and as a communications network within the system. This means that the system can be built without the need for a separate wired communications infrastructure linking the BU and Receivers to the PP.
- Using just 10MHz of the available spectrum would allow up to 300 RUs to operate simultaneously in an area with a position output latency of less than one second. Accepting a greater latency in location output may enable many more RUs to operate simultaneously.
- A location carrier of up 5MHz could be used, which should yield accuracies of a few metres or better in suitable operating environments.
- Operation in an uncluttered environment could be over an area as large as 3km diameter, although it is expected that the operating range would normally be somewhat less. Operation in cluttered environments, including wooded or forested areas, is likely to be marginal.
- The system can potentially be built extremely cheaply since 2.45GHz components are becoming widely available.

A system operating in the 173MHz band may have the following key attributes:

- The 173MHz band could be used for RU location, but a separate communications network linking Receivers, BU and PP would be required.
- The RU could be extremely small and cheap.
- Using the 1MHz of available spectrum up to 100 RUs could simultaneously be tracked on a continuous basis with location latencies of one second or less. More could be supported by time multiplexing the transmissions.

- Accuracies of around 6m are expected to be possible.
- The low power nature of the band means that operational ranges are quite limited, probably 3km or slightly more.
- Operation in cluttered environments is better than 2.45GHz, but remains somewhat unpredictable.